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The Critical Flow back Velocity in Hydraulic-Fracturing Shale Gas Wells

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Abstract
The loss of prop pant during the flow back process in hydraulic fracturing treatments has been a problem for many years. The effectiveness of the fracture treatment is reduced. A well cleanup is often required to remove the unwanted proppant from the wellbore to re-establish production. Among several techniques available to reduce the prop pant loss, controlling flow back velocity within a critical range is an essential measure.
The objective of this study is to determine the critical flow back velocity under different confining pressures in the propped fractures of different thicknesses. This objective is achieved based experimental studies conducted in a specially designed apparatus.
For a fracture with a given width, the closure stress helps hold the proppant in place. This is due to the friction force that is proportional to the normal force created by the closure stress. The critical flow back velocity necessary to mobilize the proppant therefore increases with closure stress. However, the stress effect may be influenced by the shape of solid particles and friction coefficient of solid. Under the condition of constant closure stress, a narrow fracture holds proppant better than a wide fracture, resulting in increased critical flow back velocity. This is interpreted to be due to the "tighter" packing of proppant in narrow fractures.

I. Introduction

Numerous studies devoted to the loss of prop pant in the flow back process after hydraulic fracturing treatment have been published. Kerver and Graham (1964) discussed the use of concentrated viscous sodium silicate for retaining proppant in place after hydraulic fracturing. The treated proppant is consolidated in place and will not back-flow when the reservoir fluid is produced from the reservoir. Ely et al. (1990) presented their studies to discuss the use of forced closure technique combined with the use of high proppant concentration and fluid quality to control proppant flowback. They recommended high proppant concentrations and near-wellbore proppant packing in order to avoid proppant flow back. Milton-Tayler et al. (1992) conducted a laboratory study of factors affecting the stability of proppants in fractures. These factors include closure stress, rock hardness, proppant type and distribution. Almond et al. (1995) studied the effect of fluid pH and type, closure pressure during RCP curing, and downhole flow conditions on proppant flowback. Goel and Shah (1999) conducted an experiment to investigate proppant flowback by using a large scale fracturing simulator. Their experiments were performed in a slot which simulated a fracture. Their studies point out that the proppant-pack stability is highly dependent on fracturing parameters and reservoir closure stresses. Results from these experiments showed that the critical flowback rate decreases as the normal stress increases and as the fracture width increases. Parker et al. (1999) showed the generation

of flow channels as the critical flow velocity required to initiate prop pant flow back increases in a numerical prop pant-flow back model.

Guo et al. (2015) conducted an experiment to investigate the critical flow rate that will initiate proppant production during the flowback process. Their experiments were performed using a Hassler type core holder, which can hold a 2" diameter core sample up to 24" long and provide a confining pressure up to 7500 psi. The core sample was cut into two pieces and filled with proppant to simulate a fracture. Water was pumped into the core holder to simulate fracturing fluid flow back. The water flow rate was varied until the proppant pack destabilized, and sand production began. Results from their experiments showed that the critical flowback velocity increases with proppant size and closure pressure. This research comprised experimental investigations of the critical flowback velocity in simulated fractures in shale, filled with different fracture width sizes under varying confining pressure conditions. But the effect of fracture width on the critical flowback velocity was not investigated. This is done in our study and the result is presented in this paper.

II. Experimental Investigations
Experimental Setup

Figure 1 presents a schematic of experimental setup for testing the critical flowback velocity. Critical flowback velocity was experimentally investigated using a Hassler type core holder, shown in **Figure 2.** The core holder can hold a 2" diameter

core sample up to 24" long. The core holder allows for applying a confining pressure up to 7,500 psi. With the core holder assembled and the sleeve in place a core sample is inserted. Inlet and outlet distribution plugs allow fluid to be circulated through a propped fracture in the core sample. A liquid pump can provide a flow rate up to 1700 ml/min.
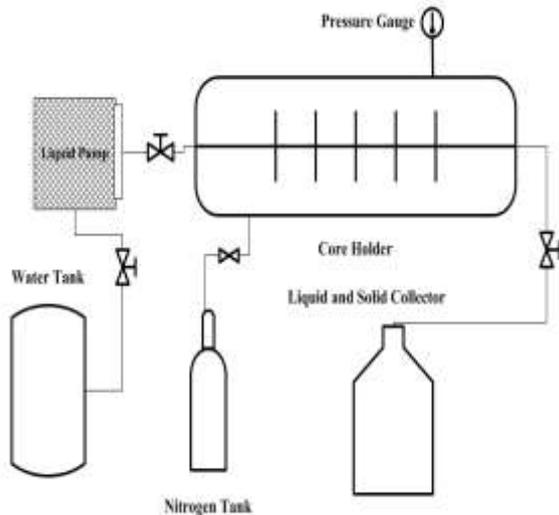

Figure 1. *Schematic Diagram of Flowback Testing Experimental System*

Figure 2. *A Hassler Type Core Holder used in the Experimental Investigation.*

Experimental Materials

A cylindrical Barnett shale rock sample 2 inches in diameter and 6 inches in length was used in the experiments. The shale core sample was cut into two equal parts and proppant was placed between the two pieces to simulate a "propped" fracture. **Figure 3** illustrates a core sample ready for testing. Four "fractured" core samples were joined together to form a total length of 24 inches. **Figure 4** depicts the flow of fluid in the core holder.

Figure 3. *"Fractured" Core Sample with Proppant Inserted.*

Figure 4. *Flow Path inside Core Sample.*

Experimental Design

Three fracture thicknesses, 0.05 inch, 0.1 inch and 0.15 inch were used in the experiments. The proppant sample used was 40/70 mesh natural sand. **Table 1** shows the parameters calculated for the fracture in each core section:

Table 1. Parameter Values of Fracture and Proppant

Fracture height (in.)	2
Fracture length (in.)	6
Fracture surface area (ft^2)	0.083
Weight of proppant (lb)	0.038
Proppant concentration (lb/ft^2)	0.458
Width of fracture (in.)	0.05,0.1, 0.15
Cross-sectional area of fracture (in^2.)	0.1, 0.2, 0.3

The experiments were run on the 40/70 mesh sand at confining pressures ranging from 80 psi to 800 psi to simulate the effective stress in the sand pack. Water injection rate was varied from 0 ml/min to 1700 ml/min. Water and proppant were collected at the outlet and mass flow rate was calculated.

III. Result

Figure 5 summarizes the experimental results for a 0.05 inch fracture at different confining pressures. It shows that the critical flowback velocity is not affected by the confining pressure. High confining pressure can hold proppant tighter and thus increase the critical flowback velocity.
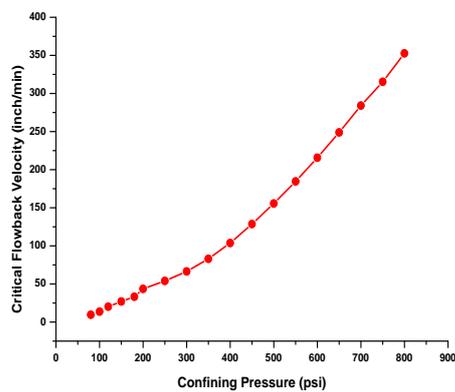

Figure 5. Effect of Confining Pressure on the Critical Flowback Velocity in a Fracture of 0.05 inch Thickness

Figure 6 presents the experimental result for a fracture of thickness 0.1 inch. It shows that the critical flowback velocity is non-linearly affected by the confining pressure.
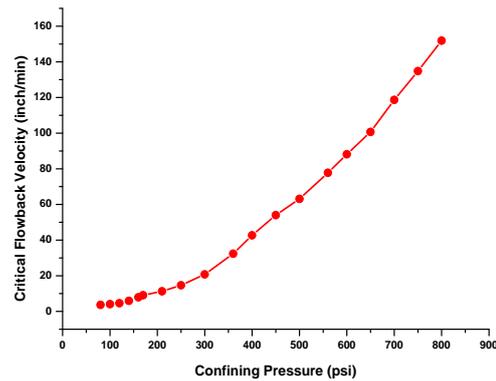

Figure 6. Effect of Confining Pressure on the Critical Flowback Velocity in a Fracture of 0.1 inch Thickness

Figure 7 presents the experimental results for a fracture with thickness of 0.15 inch. It shows that the critical flowback velocity is non-linearly affected by the confining pressure.
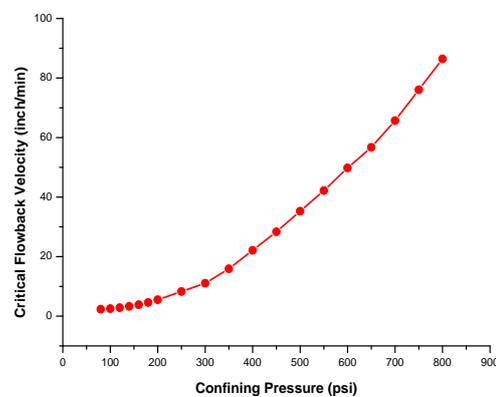

Figure 7. Effect of Confining Pressure on the Critical Flowback Velocity in a Fracture with a Fracture Thickness of 0.15 inch.

A comparison for the critical flowback velocities in fractures of three thickness can be seen in **Figure 8**. The critical flow velocities are 9.64 in/min, 3.66 in/min and 2.34 in/min when the confining pressure is 80 psi. When the confining pressure was increased to 800 psi, the critical flowback velocities changed to be 352.58 in/min, 151.89 in/min and 86.42 in/min, respectively. The critical flowback velocity does not drop linearly with fracture thickness.
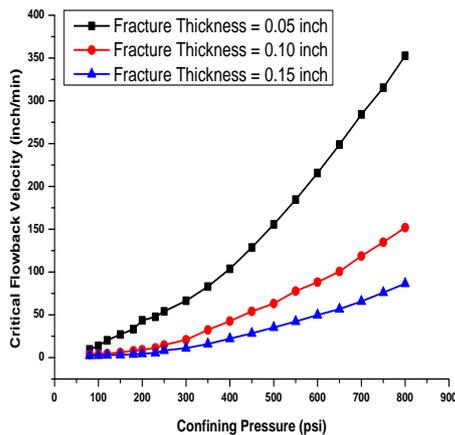
Figure 8. The Comparison between Three Different Thicknesses of Fractures.

IV. Discussion

Stability of proppant pack is dominated by the balance between the driving hydrodynamic force, the gravitational force, and the resisting friction force (Pearson and Zazovsky, 1997). Previous studies have shown that the closure stress and hydrodynamic force are the two mechanisms that contribute to proppant flowback. Higher closure stresses increased the normal forces acting to extrude proppant grains out of the fracture. But our study shows that the closure stress hinders proppant flowback. As the confining pressure applied to the proppant through the core holder sleeve increased, the frictional force within the proppant grains also increased, which made the proppant pack more stable. The hydrodynamic force is resisted by frictional resistance and cohesion. This is demonstrated in **Figure 9**.
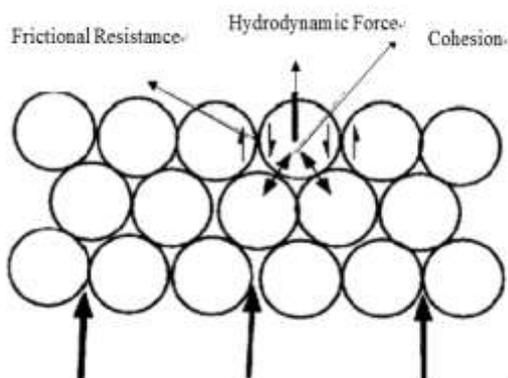

Figure 9. Forces Acting On Particles at the Surface of the Perforation Tunnel (Pearson and Zazovsky, 1997)

The discrepancy between the results from this and previous study is explained as the difference in experimental materials. As interpreted by Guo et al. (2015), the closure pressure can increase or decrease the critical flow back velocity depending on friction coefficient. Closure pressure can squeeze the proppant out of the fracture if the friction coefficient is low. But it can hold the proppant in the fracture if the friction coefficient is high enough.

V. Conclusions

An experimental investigation has been conducted to study the critical flowback velocity in hydraulic-fracturing shale gas wells. The following conclusions are drawn:

1. For a fracture with a given width, the closure stress helps holding the proppant in place. This is due to the friction force that is proportional to the normal force created by the closure stress. The critical flowback velocity necessary to mobilize the proppant therefore increases with closure stress. However, the stress effect may be influenced by the shape of solid particles and friction coefficient of solid. More experiments with various types of proppant should be conducted to understand this effect.
2. Under the condition of constant closure stress, a narrow fracture holds proppant better than a wide fracture, resulting in increased critical flowback velocity. This is interpreted to be due the "tighter" packing of proppant in narrow fractures.

VI. Acknowledgements

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